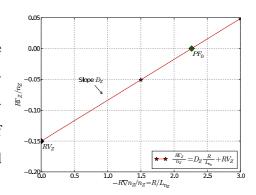
# Impurity transport in ITG and TE mode dominated turbulence

A. Skyman<sup>1</sup>, H. Nordman<sup>1</sup>, P. Strand<sup>1</sup>, F. Jenko<sup>2</sup>, F. Merz<sup>2</sup>

## Introduction

The transport properties of impurities is of high relevance for the performance and optimisation of magnetic fusion devices. For instance, if impurities from the plasmafacing surfaces accumulate in the core, wall-impurities of relatively low density suffice to dilute the plasma and lead to unacceptable energy losses in the form of radiation.



In the present study, turbulent impurity transport in Deuterium tokamak plasmas, driven by Ion Temperature Gradient (ITG) and Trapped Electron (TE) modes, has

Figure 1: Illustration of  $PF_0$  and the linearity of  $\Gamma_Z$  ( $\nabla n_Z$ ); ITG dominated quasilinear GENE result for Ne with  $k\rho = 0.3$ 

been investigated using fluid and gyrokinetic models. The impurity diffusivity  $(D_Z)$  and convective velocity  $(V_Z)$  are calculated, and from these the zero-flux peaking factor  $(PF_0)$  is derived. This quantity expresses the impurity density gradient at which the convective and diffusive transport of impurities are exactly balanced. The sign of  $PF_0$  is of special interest, as it determines whether the impurities are subject to an inward  $(PF_0 > 0)$  or outward  $(PF_0 < 0)$  pinch.

Quasilinear results obtained from the GENE code [1, 2] are compared with two-fluid results [3] for both ITG and TE mode dominated turbulence. Scalings of  $PF_0$  with impurity charge (Z) and various plasma parameters, such as magnetic shear ( $\hat{s}$ ), are studied. Of particular interest are conditions favouring an outward convective impurity flux.

## Theoretical background

The transport of a trace impurity species can locally be described by a diffusive and a convective part. The former is characterized by the diffusion coefficient  $D_Z$ , the latter by a convective velocity or "pinch"  $V_Z$ , see equation (1) [4]. From these, the zero flux peaking factor is defined as  $PF_0 = \frac{-RV_Z}{D_Z}|_{\Gamma=0}$ , see figure 1.  $PF_0$  is important in reactor design, as it quantifies the balance of convective and diffusive transport. This can be seen from equation (1), where  $\Gamma_Z$  is the impurity flux,  $n_Z$  the density of the impurity species and R the major radius of the tokamak.

<sup>&</sup>lt;sup>1</sup> Euratom-VR Association, Department of Radio and Space Science, Chalmers University of Technology, SE-412 96 Göteborg, Sweden.

<sup>&</sup>lt;sup>2</sup> Max-Planck-Institut für Plasmaphysik EURATOM-IPP, D-85748 Garching, Germany.

For the domain studied – a narrow flux tube – the gradient of the impurity density is constant:  $\nabla n_Z/n_Z = 1/L_{n_Z}$ . Setting  $\Gamma_Z = 0$  in equation (1) yields the interpretation of  $PF_0$  as the gradient of zero impurity flux.

$$\Gamma_Z = -D_Z \nabla n_Z + n_Z V_Z \Leftrightarrow \frac{R\Gamma}{n_Z} = -D_Z \frac{R}{L_{n_Z}} + RV_Z \tag{1}$$

### Fluid model

Though the main results presented in this study have been obtained using quasilinear gyrokinetic simulations, their physical meaning is interpreted by comparing with the Weiland multi-fluid model [3]. The fluid equations for each included species (j = i, te, Z, representing Deuterium ions, trapped electrons, and trace impurities) are:

$$\frac{\partial n_j}{\partial t} + \nabla \cdot (n_j \mathbf{v}_j) = 0 \tag{2}$$

$$m_{i,Z}n_{i,Z}\frac{\partial v_{|i,Z}}{\partial t} + \nabla_{||}\left(n_{i,Z}T_{i,Z}\right) + n_{i,Z}e\nabla_{||}\varphi = 0$$
(3)

$$\frac{3}{2}n_j\frac{\mathrm{d}T_j}{\mathrm{d}t} + n_jT_j\nabla\cdot\boldsymbol{v}_j + \nabla\cdot\boldsymbol{q}_j = 0$$
(4)

Here  $q_j$  is the diamagnetic heat flux, and  $v_j$  is the sum of the  $E \times B$ , diamagnetic drift, polarization drift, and stress-tensor drift velocities. To solve the equations, it is assumed that  $q_j$  is the only heat flux for all species, that passing electrons are adiabatic, and that quasineutrality (equation (5)) holds. Going to the trace limit for the impurities, i.e. letting  $Zf_Z \to 0$  in equation (5), an eigenvalue equation for ITG and TE modes is obtained. The impurity particle flux in equation (1) is then obtained from  $\Gamma_{nj} = \langle \delta n_j v_{E \times B} \rangle$ , where the averaging is performed over all unstable modes for a fixed length scale  $k\rho$  of the turbulence.

$$\frac{\delta n_e}{n_e} = (1 - Zf_Z) \frac{\delta n_i}{n_i} + Zf_Z \frac{\delta n_Z}{n_Z}, \quad f_Z = \frac{n_Z}{n_e}$$
 (5)

## Quasilinear gyrokinetic simulations

GENE is a parallel gyrokinetic code employing a fixed grid in five dimensional phase space and a flux-tube geometry [1]. The simulations were performed on the *HPC-FF* cluster<sup>1</sup> with GENE running in eigenvalue mode. Growth rates and impurity fluxes were thus computed for ITG and TE mode dominated cases, for which a number of parameters were varied and trends observed. The main parameters used are presented in table 1.

<sup>1</sup>HPC-FF (*High Performance Computing For Fusion*) is an EFDA funded computer situated at Forschungszentrum Jülich. Germany, dedicated to fusion research

Table 1: Parameters used in all simulations

	ITG:	TEM:
$T_D/T_e$ :	1.0	1.0
ŝ:	0.8	0.8
$q_0$ :	1.4	1.4
ε:	0.14	0.14
$R/L_{T_D}$ , $R/L_{T_Z}$ :	7.0	3.0
$R/L_{T_e}$ :	3.0	7.0
$N_x \times N_{ky} \times N_z$ :	$5 \times 1 \times 24$	$4 \times 1 \times 24$
$N_{v_{  }} \times N_{\mu}$ :	$64 \times 12$	$64 \times 12$

## **Results**

**Impurity charge** Z: The main results obtained are the scalings of the peaking factor with the charge of the impurity species. These are presented in figures 2(a) and 2(b), showing ITG and TE mode dominated turbulence respectively.

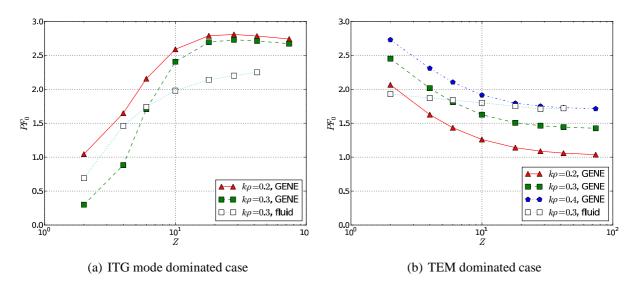


Figure 2: Scalings of  $PF_0$  with impurity charge Z; quasilinear GENE and fluid results

The difference between figure 2(a) and 2(b) can be understood from the properties of the convective velocity in (1).  $V_Z$  contains a thermodiffusive term  $V_{T_Z} \sim \frac{1}{Z} \frac{R}{L_{T_Z}}$  and a parallel impurity compression term  $V_{p_Z} \sim \frac{Z}{A_Z} k_{||}^2 \sim \frac{Z}{A_Z q^2}$ . The former is generally outward  $(V_{T_Z} > 0)$  for ITG and inward  $(V_{T_Z} < 0)$  for TE mode dominated transport, whereas for the latter the opposite is generally the case.

Magnetic shear  $\hat{s}$ : The effect of magnetic shear on the peaking factor is shown in figures 3(a) and 3(b). It is worth noting that a flux reversal, i.e. a change of sign in  $PF_0$ , owing to a change in sign of  $V_Z$ , occurs for negative  $\hat{s}$  for  $Z\gtrsim 6$  in the TE mode dominated case, indicating a net outward transport of the heavier elements. Similar trends are not seen in fluid simulations, and this warrants further investigation.

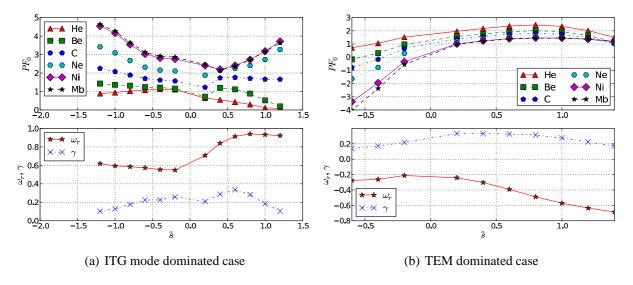


Figure 3: Scalings of  $PF_0$  with magnetic shearing  $\hat{s}$ ; quasilinear GENE results with  $k\rho = 0.3$ 

Other parameters: Scans of the dependence  $PF_0$  on other parameters, such as  $k\rho$  and  $L_T$ , have also been carried out. The results are similar to those reported in [5], [6] and [7] respectively. In most cases, only a weak dependence of  $PF_0$  is observed.

### **Conclusions and outlook**

Quasilinear GENE simulations and fluid results show that peaking factor increases with impurity charge Z for ITG mode dominated transport, whereas the opposite holds for TE mode dominated transport. In both cases  $PF_0$  saturates for high Z.

For magnetic shear, a flux reversal is observed for negative magnetic shear in the TEM dominated case. This is not seen in fluid simulations, and will be a focus of future studies.

For other parameters investigated, weak scalings for  $PF_0$  are observed, in agreement with previous work.

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